ELECTRIC-POWER-DISTRIBUTION SYSTEM, POTASH MINE AND REFINERY, DUVAL SULPHUR & POTASH COMPANY, CARLSBAD, N. MEX.

BY J. HOWARD BIRD AND A. Z. DIMITROFF

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ELECTRIC-POWER-DISTRIBUTION SYSTEM, POTASH MINE AND REFINERY, DUVAL SULPHUR & POTASH COMPANY, CARLSBAD, N. MEX.[1]

by

J. Howard Bird[2] and A. Z. Dimitroff[3]

SUMMARY AND INTRODUCTION

The purpose of this publication is to describe the power-distribution system of the mine and refinery of the Duval Sulphur & Potash Company at Carlsbad, N. Mex. This distribution system has been excellently predesigned to meet requirements and fit special conditions encountered at the property. In presenting the material, the authors point out various features that would be desirable for incorporation in other systems under similar conditions.

Central location of switchgear in pressurized vaults and ventilation of such equipment with filtered air prevent salt accumulations and contribute to trouble-free operation. The simplification of power-distribution circuits and overload protection, as a result of centralization of switchgear, the use of individual control circuits enclosed in conduit (which aids troubleshooting), and central location of control panels, are factors which contribute to efficient, safe operation. Those features are applicable to many operations where fire or explosion hazards are encountered, or where dusty conditions may exist, as well as in operations where numerous individual drives are involved.

Both wye-connected and delta-connected secondaries are used in distributing secondary power. The wye-connected transformer secondary windings have solidly grounded neutrals and distribute power to the surface equipment and stationary underground equipment. Faults are effectively isolated by the overload devices. Delta-connected secondaries with derived neutrals serve all underground mobile and portable alternating-current equipment. Ground-fault protection is provided on this system through relays which operate on 3.5-ampere current values. Two schemes of ground-fault protection are used. In one the ground-current trip relay is in series with the frame grounding conductor, while in the other a ring-type transformer is used, which operates on current unbalance of the circuit. The latter system minimizes interference from ground-circulating currents and is more selective.

1/ Work on manuscript completed January 1959.

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The advantage of a well-designed, properly installed, and adequately maintained power-distribution system is reflected in the efficient, trouble-free, safe operation of electrical equipment at this property.

With the marked increase of mechanization in mining and the ever-increasing size of individual machines, the electric power demand at the point of utilization is such that the economic, efficient, safe distribution of electrical energy is one of the key factors in a profitable operation. Unfortunately, in many cases, the power distribution system is not predesigned but is expected to grow with development of the property. This results in an inefficient power distribution system as well as a costly one.

The advantages of using alternating-current power underground in connection with face equipment has been recognized and accepted by many operators.

Considerable information is available on alternating-current power-distribution systems and the advantages and disadvantages of various transformer connections. However, until recently the mining industry in general has been reluctant to accept some of these "new" ideas, or rather to put them into practice. Neutral grounding of power systems has been more or less accepted by industry as having some advantages over ungrounded systems from the operational standpoint, and yet until recently it had not been considered in mining operations. Even today providing a derived ground on delta-connected secondaries for grounding of alternating-current equipment to minimize ground faults is not generally practiced in conjunction with underground mine distribution systems. This is perhaps due to the fact that in many mines, particularly coal mines, most portable and mobile equipment was powered by direct current. Alternating-current power was used primarily in connection with stationary equipment which was more or less permanently installed. Such equipment was generally frame-grounded without ground-fault relay protection.

The gradual displacement of direct-current-powered equipment with equipment using alternating-current power, in the higher utilization voltage ranges, has focused the attention of design engineers and operating personnel on distribution systems that provide better control of ground faults, minimize damage to equipment insulation, provide safety to personnel from shock hazards, and lend themselves to proper sectionalization and location of faults.

The power-distribution system of the mine and refinery of the Duval Sulphur & Potash Company at Carlsbad, N. Mex., is excellently designed to meet the above requirements and to fit the operation. In blueprinting the distribution system, before development of the property, provisions were made for the maximum anticipated load demands. Various other conditions peculiar to the operation, which had a bearing on the proper operation of the power-distribution system, were taken into consideration. It is the authors' belief that a description of the system would be of interest, and that some of the features of this distribution system and practices are applicable to other operations and would be worth while adopting.

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ACKNOWLEDGMENTS

The authors wish to acknowledge the interest and help of J. E. Tong, resident manager, in arranging for a visit to the property and granting permission to describe the power-distribution system.

Acknowledgment is made to A. T. Jones, superintendent of maintenance and construction, for his assistance in describing the system and his help in assembling data and photographs.

Credit is due H. A. London, former superintendent of maintenance and construction, who was instrumental in the design of the power system, and under whose supervision the system was put into operation. His explanation of the various problems and unusual conditions encountered in connection with power distribution at this property were very helpful to the authors.

MINING OPERATION AND UNUSUAL CONDITIONS

Mining of potash ore was started by the Duval Sulphur & Potash Company in December 1951. The mine and refinery are in Eddy County, N. Mex., about 21 miles east of Carlsbad. The mine was developed through two vertical, concrete-lined shafts about 300 feet apart. The ore bed, which is 6 to 14 feet thick, is at a depth of about 1,400 feet at the shafts. The ore is mined by a systematic room-and-pillar method. Entries are driven in sets of three, and the mining areas are divided into panels with barrier pillars between them.

The ore mined is sylvinite, a mixture of sylvite (KCl) and halite (NaCl). It is interesting to note that the sylvinite ore, if dry, is a very poor conductor of electric current. The resistance of the sylvinite is lowered with the increase of impurity, which in this case is halite. Table 1 gives some resistance measurements made in sylvinite-ore deposits.4/ The measurements were made by driving copper rods a given distance apart in the same vertical plane.

TABLE 1. - Resistance measurements

Location of rods	Spacing, inches	Ohms
High-grade sylvinite ore.....	12	7 million
Low-grade sylvinite ore.....	12	550
Rod A in high-grade sylvinite 3 feet above floor).. Rod B in floor 2 feet from face)	60	135,000
Rod A in low-grade sylvinite 4 feet above floor).. Rod B in floor 2 feet from face)	72	3,500

4/ Hyvarinan, J., Mining-Electrical Survey, Potash Mine and Refinery of Potash Division, International Minerals and Chemical Corporation: Bureau of Mines, June 1946.

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Even though the resistance is lowered considerably by impurities, it remains fairly high until moisture is introduced. Obviously, with the increase of moisture the resistance of the salt is rapidly decreased.

The mine is dry, and little or no moisture is encountered during mining. Furthermore, owing to the dry climate of this area, damaging amounts of moisture are seldom introduced in the mine over the ventilation system. The inherent characteristics of the salt present a considerable problem on the surface. It has been the experience in the potash field that during damp weather outages often result, and serious damage to switchgear and equipment is inflicted by flashovers if salt dust is permitted to accumulate. In the design of the surface plant, therefore, provision was made to prevent the accumulation of salt dust on electrical switchgear, which is sensitive to this type of damage. The means used to accomplish this are pressurized vaults or rooms, which receive filtered intake air for ventilation. Figure 1 shows the inside

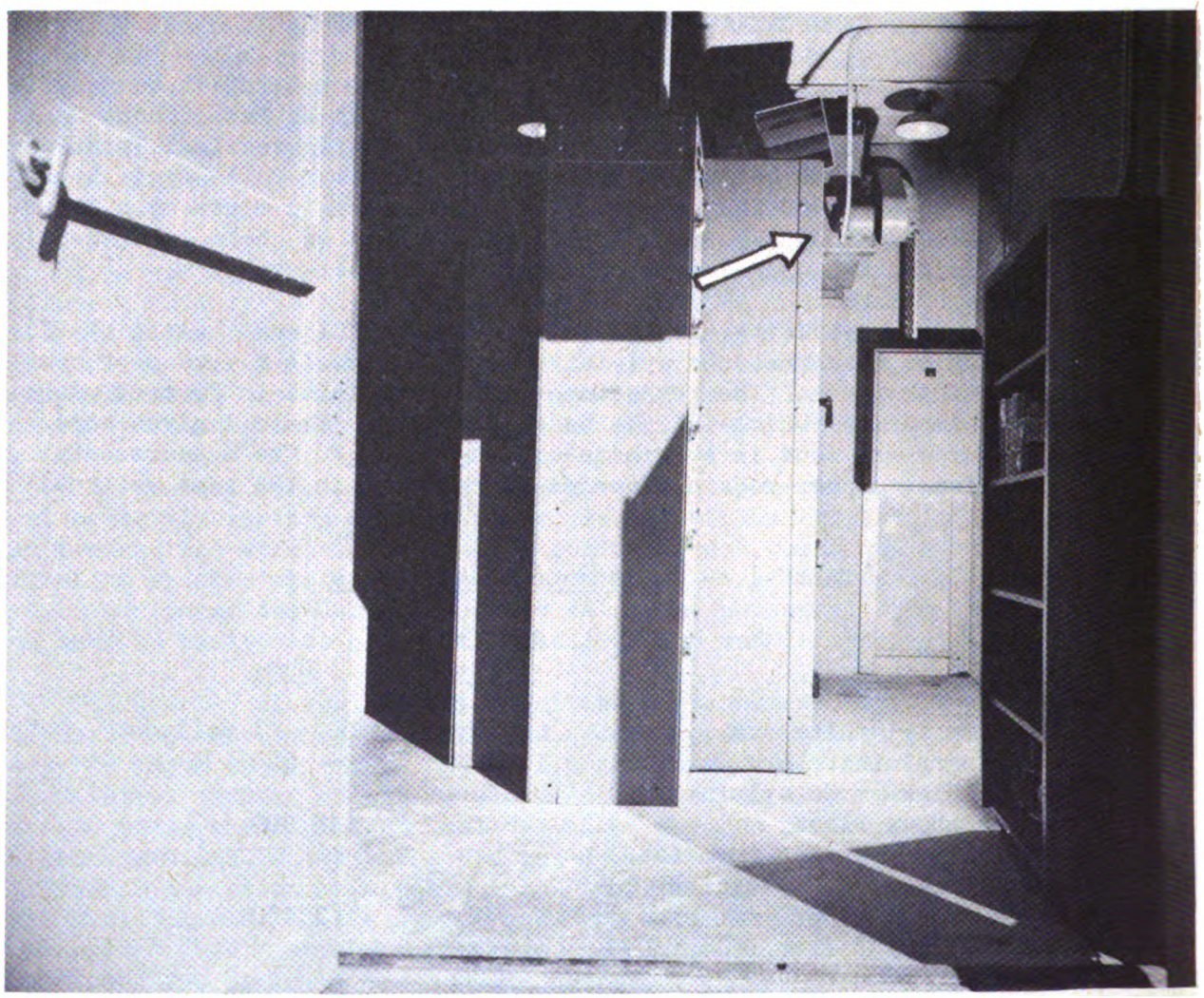

FIGURE 1. - Crusher Area Motor Control Room. View Through Vault Door Shows Ventilating Fan (arrow) Near Ceiling on Rear Wall.

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of a vault containing switchgear, as viewed through the door. The fan used to ventilate the vault is located on the back wall. Figure 2 shows the intake-air filter for this vault which is equipped with a manometer.

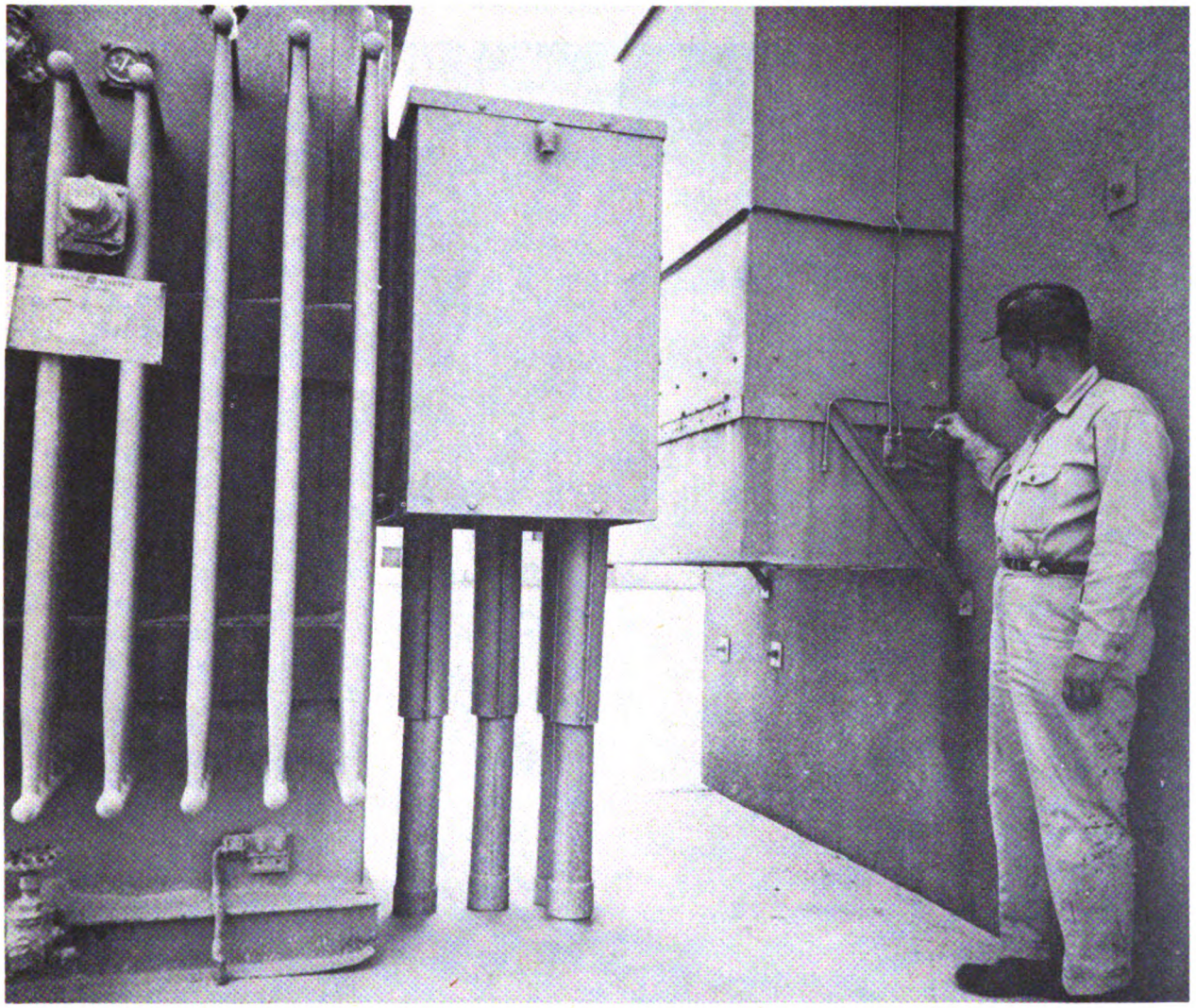

FIGURE 2. - Man Pointing to Manometer. Crusher Area Transformer and Filter for Controlling Vault Pressurizing Fan.

The manometer is used to signal when a predetermined pressure differential is reached, at which time the air filter is replaced or cleaned. The fan supplying air to the vault operates continuously.

The switchgear for the electrical equipment and power supply for the refinery are contained in an L-shaped, pressurized room. This room is on the main floor inside the refinery building. Figure 3 shows the main feeders and

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circuit breakers as viewed through the door. The inside of the same section of the room is shown on figure 4. The ventilating fan can be observed on the back wall. Figures 5 and 6 show the switchgear in the other portion of the room. The panels are back-to-back, located in the center of the room, and consist of individual metal cubicles. Although these vaults have been designed to provide protection under special conditions, it is clear that the features which they offer would be desirable under other operating conditions. Central location of the switchgear, isolation from dust accumulation, accessibility to maintenance without interference with other operations; and the simplification of power distribution circuits and overload protection, are factors that unquestionably contribute to an efficient and safe operation. In coal-mine tipples and washers, where dusty conditions are encountered; and where fire or explosion hazards owing to dust exist, such an installation would be a definite asset.

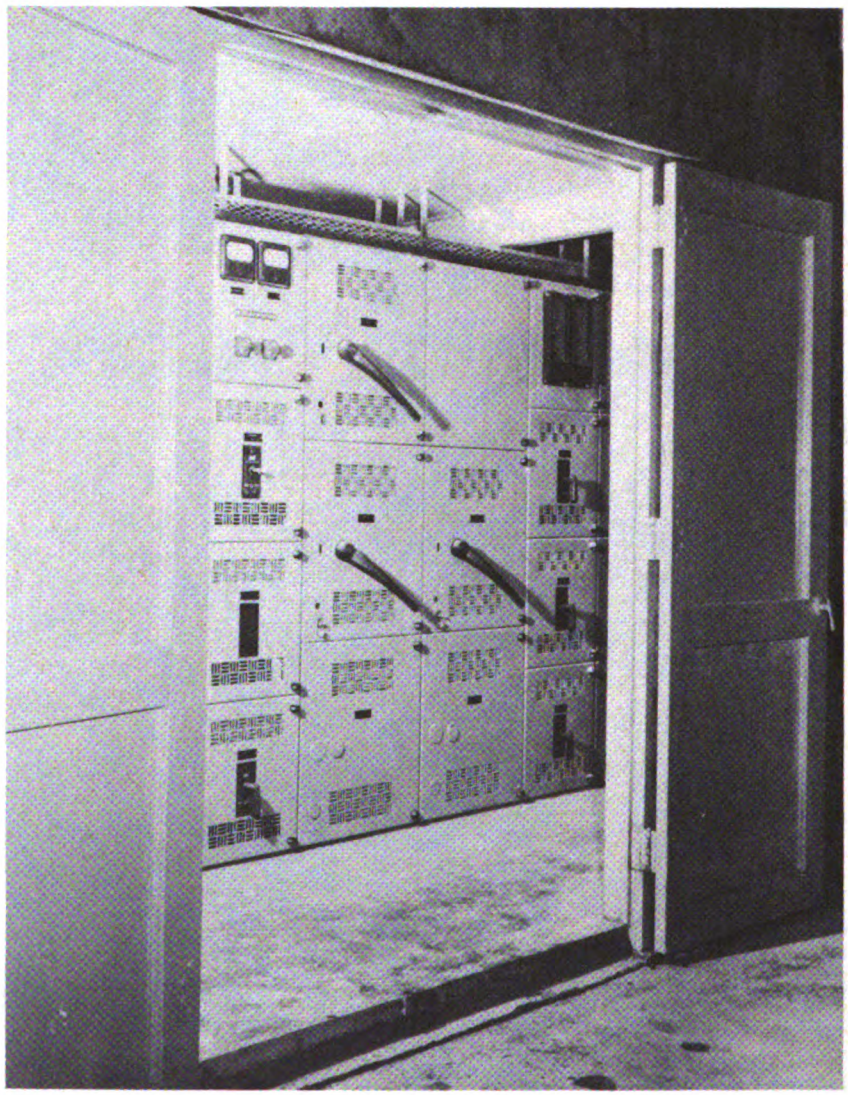

FIGURE 3. - Refinery Main Feeder Control Room, Seen Through South Door of Pressurized Vault.

The control panels for the various equipment are located throughout the refinery according to function. Figure 7 is a view of the top deck showing the wet-grinding and classifier control panel. Figure 8 shows the steam-generation and drier control panels. Each control circuit for a given operation is individually enclosed in conduit leading to the central switchgear vault. This simplifies trouble shooting and repairs in case of a fault, and eliminates interference with other operations.

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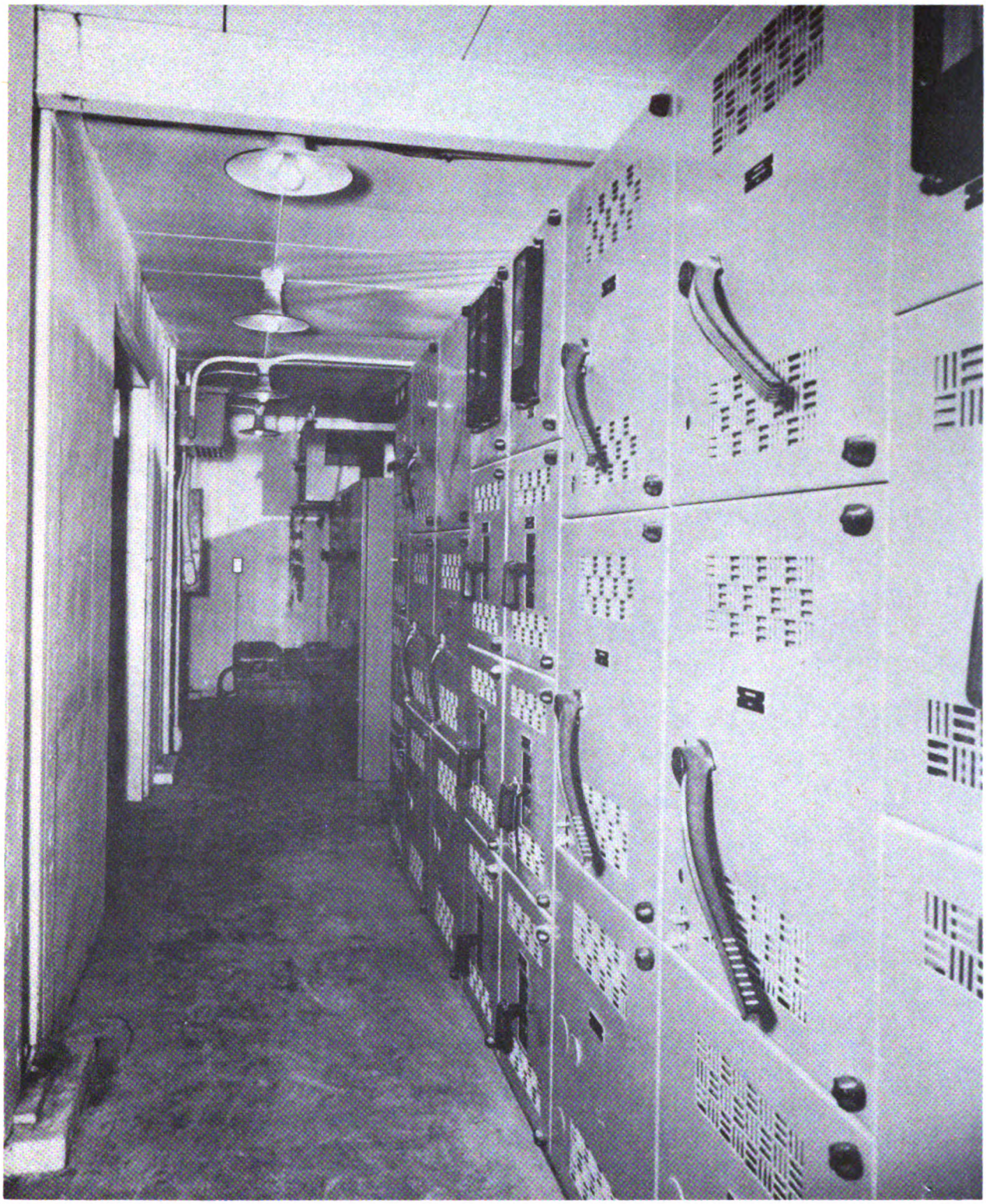

FIGURE 4. - Refinery Low-Voltage Switchgear and Two Synchronous Motor Control Cubicles. Ventilating Fan Is at Far End.

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FIGURE 5. - East Side of Refinery Motor Control Center. Arrow Points to Lockout Tag and Starter Unit.

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FIGURE 6. - West Side of Refinery Motor Control Center.

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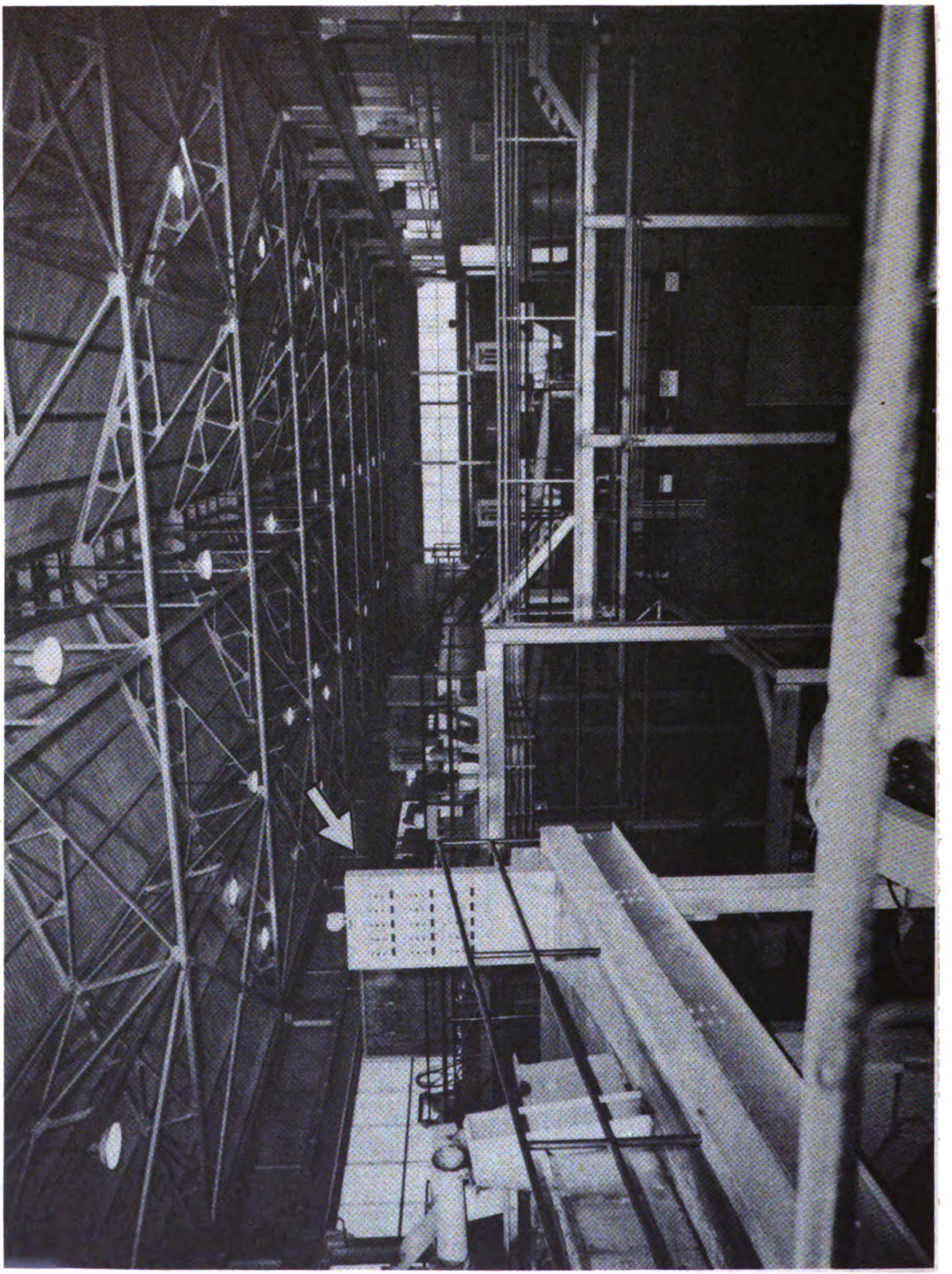

FIGURE 7. - Refinery Top Deck Showing Wet Grinding and Classifier Control Panel (arrow).

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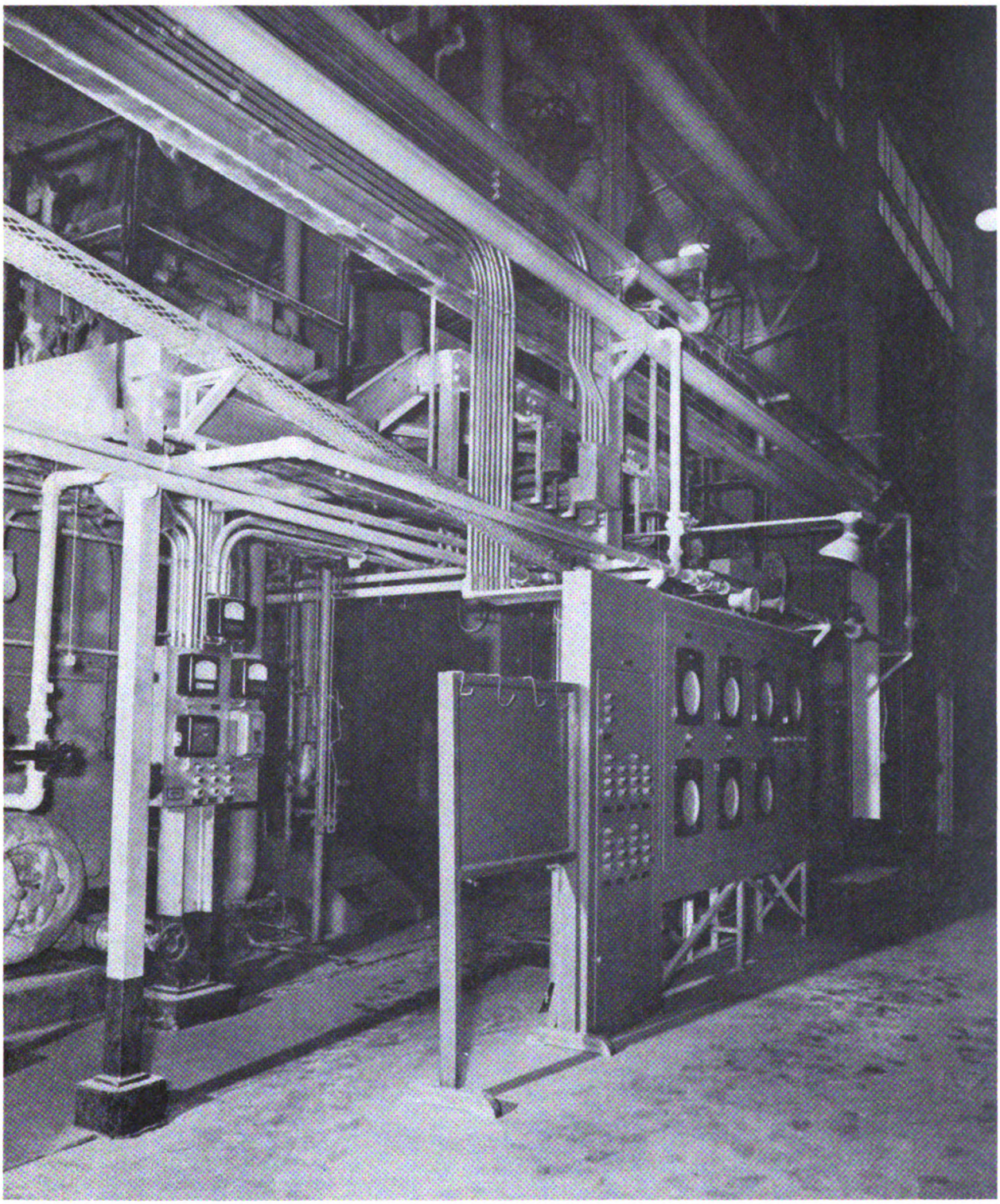

FIGURE 8. - Steam Generation and Dryer Control Panel Showing Conduit Installation for Individual Control Circuits.

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PRIMARY DISTRIBUTION

Three-phase, 60-cycle power was received at the power-company transformer station at 69,000 volts and was reduced to 4,160 volts for delivery to the mining company. The power-company transformer was connected delta-wye with a grounded neutral through a resistor that would limit fault currents to 200 amperes. Two power feeders, each consisting of three lead-covered single conductors and a ground conductor, installed in a concrete-encased duct, transmit the power to the hoisthouse, whence it is dispatched to various points. Each one of the two main feeders, as well as the two feeders delivering power underground, is provided with phase overcurrent relays, in addition to the reverse-current relays, and the ground fault relay. Thus, a phase-to-ground fault in either power feeder can be isolated immediately and the feeder is taken out of service. The carrying capacity of the power feeders is such that, in case of an outage, the load can be carried by only one feeder.

Figure 9 shows the switchgear and relays in the hoisthouse of the incoming power feeders and outgoing feeders. Power to substations on the surface and underground is dispatched from this point. Figures 10 and 11 are views of the underground substation where power is received from the surface. The incoming feeder can be seen in figure 11 on the right side over the cabinet. The device shown in the foreground is a circuit-breaker transfer cart used in handling the removable breakers during servicing. In the background, behind the resuscitation chart, can be seen a battery of cells providing power for switching and pilot lights.

The two feeders supplying power underground were installed in separate shafts. They were three-conductor, 3/0 AWG, shielded, steel-armored cables. Primary power at 4,160 volts was distributed through the mine over three-conductor, 2/0 AWG, 5,000-volt type-G shielded nonmetallic sheathed cables.

SECONDARY DISTRIBUTION

All face equipment except the shuttle cars, three machinery moving trucks, and the diesel equipment was operated on 440-volt alternating-current power. The stationary equipment, such as belt-conveyor drives, elevating conveyors, and crushers, was also operated on 440-volt alternating-current power. Power at 120 and 240 volts was used for lighting. Handheld equipment was operated on 240 volts. Power was supplied to the mobile and portable face equipment by transformers with delta-connected secondaries, while the stationary equipment underground, as well as the equipment of the surface plant, was served by transformers having wye-connected secondaries. The neutrals of the wye-connected transformers were solidly grounded.

There has been considerable difference of opinion among engineers on the merits of grounded and ungrounded alternating-current systems. Perhaps the most common reason cited by mining men in favor of ungrounded, three-phase, alternating-current systems is their ability to function without an outage when a contact is established from one phase to ground. Furthermore, it is pointed out that the initial cost of a grounded system is higher. These factors in themselves appear to be valid and on the surface present a strong

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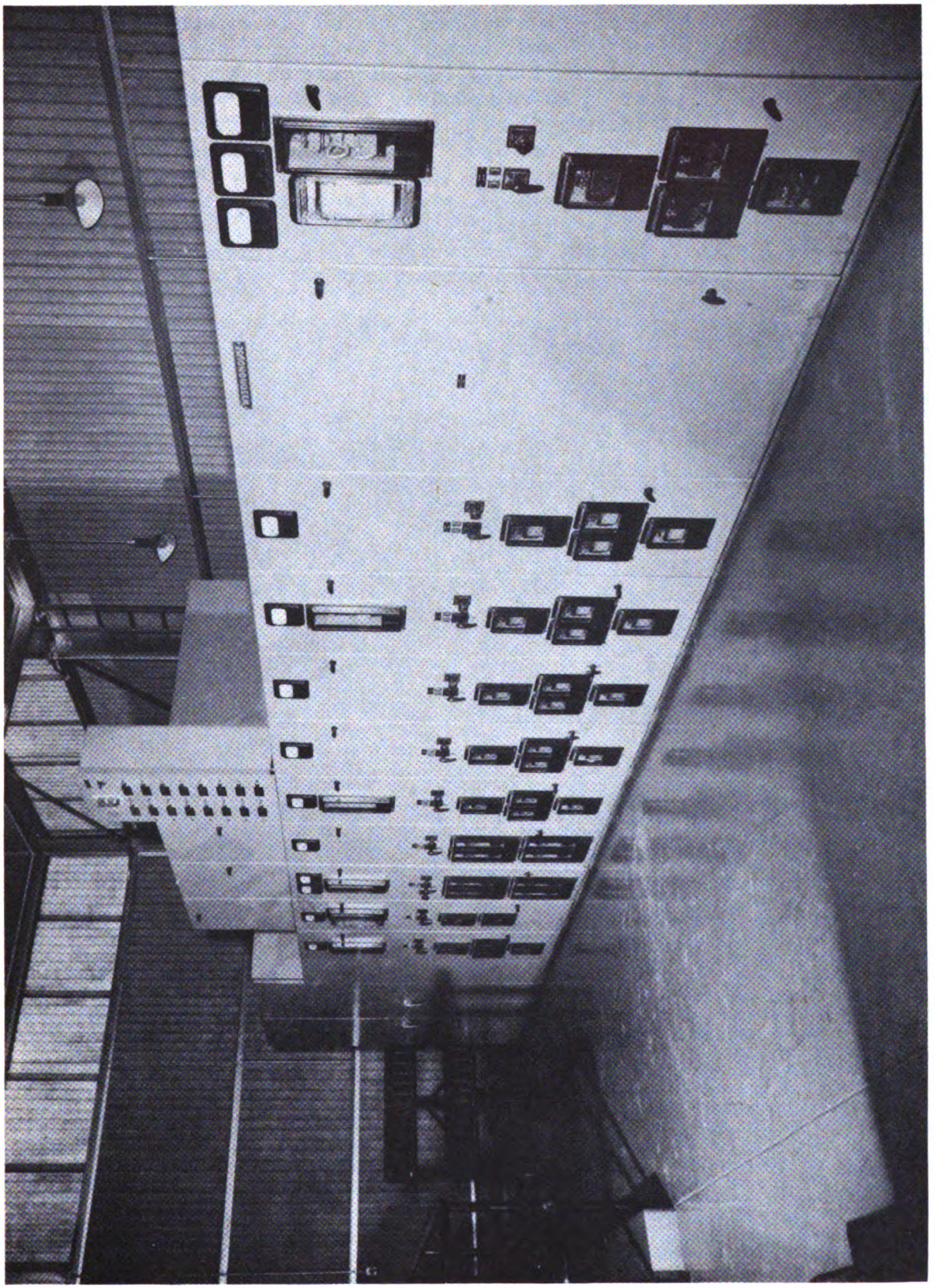

FIGURE 9. - Central High-Voltage Switchgear Installation at Hoisthouse. Target Alarm Panel Is on Top of Switchgear Cabinets.

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argument for the use of ungrounded-type systems. It should be noted, however, that when outages over a period of time, damage to equipment, safety to personnel, and overall maintenance are considered, the picture changes. If a fault to ground is permitted to exist on an ungrounded, three-phase system, the possibility of another fault is increased; and, in turn, such a fault can do severe damage and result in a longer outage. This is true because, if the ground faults are on different phases, full line potential may be established between the two points. On the other hand, since the earth's resistance is usually high, the impressed voltage on two sections of earth or mine strata may not be cleared by the protective devices. This will surely result in a dangerous shock-hazard and fire-hazard condition. Consequently, as regards

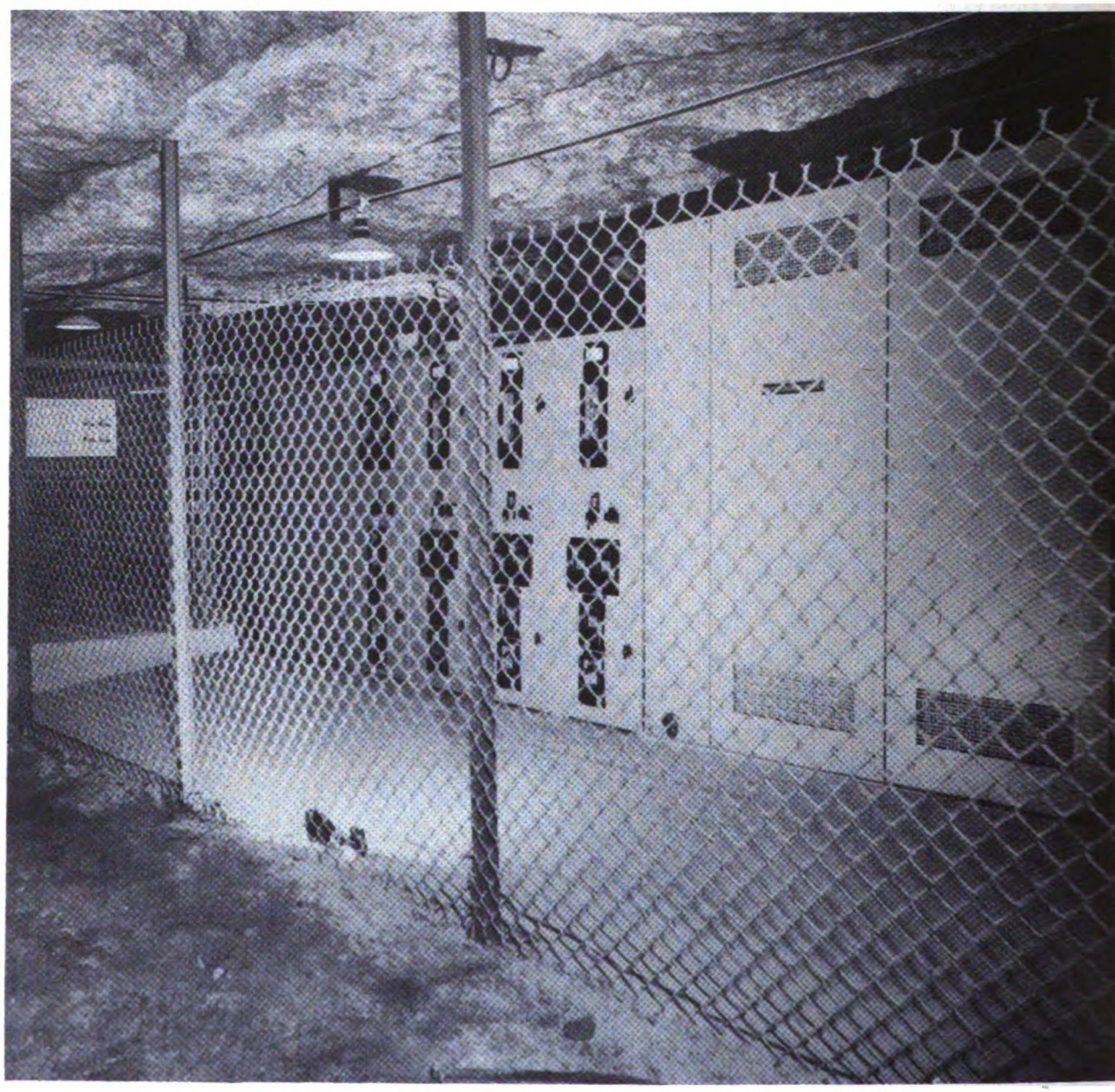

FIGURE 10. - High-Voltage Switchgear Underground Installation. Note Protective Fencing.

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maintenance, a more thorough program is needed if the advantage of no outage is to be applicable. The ability to immediately locate and isolate a ground fault, a quality to which a grounded system lends itself, is an advantage much to be desired. The foregone discussion pertains to three-phase power systems. It does not apply to single-phase systems, isolated from the ground, the advantages of which, with respect to minimizing shock hazard to personnel, are well recognized.

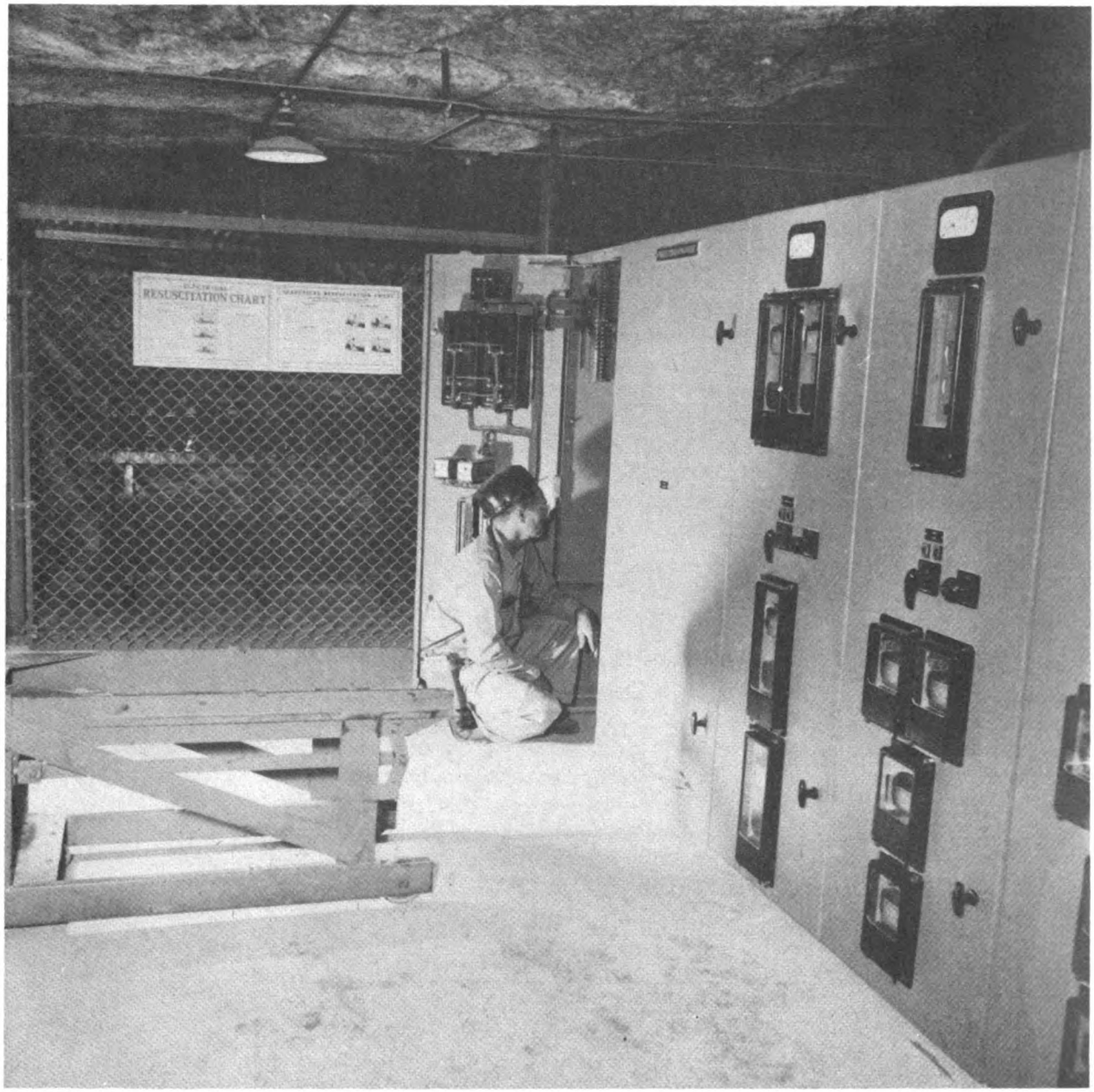

FIGURE 11. - High-Voltage Switchgear Underground. Breaker Transfer Cart and Batteries for Switching Are in Area Behind Resuscitation Chart at Far End.

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The type of power center, shown in figure 12, rated at 225 kv.-a., is used to supply power, at 440 volts, to the face equipment. The normal connected load to these power centers is as follows:

	Hp.
1 loading machine.....	75
1 cutting machine.....	50
1 jumbo drill.....	26
8 blower fans.....	40
Total.....	191

At times the crusher and elevating conveyor load, consisting of 100 hp., is added to this load, making a total of 291 hp. on a mine power center. This is seldom done, however, and the experience has been that, due to the diversity factor of the connected equipment, operation is satisfactory. Normally the crusher and elevating conveyor at a belt-loading point are served by 112.5 kv.-a. transformers.

The power centers are equipped with four circuit breakers that distribute secondary power to the equipment with a lighting circuit breaker. The thermal elements of the equipment circuit breakers are rated at 225 amperes. The instantaneous (magnetic) trips of these circuit breakers are adjustable from 700 to 2,250 amperes. Minimum settings of the magnetic trips and minimum thermal-trip units, consistent with proper operation of the equipment, provide maximum possible phase-fault protection. Figure 12 is a typical underground installation of a power center and two rectifier units. The four circuit breakers of the power-center unit are visible.

Power from the power center is transmitted over 2/0, three-conductor, type G cable to a reel in the face area, to which the face-equipment trailing cables are connected. The reels are used for cable storage and provided with "gang"-type connectors, which permit connecting more than one machine to one feeder. Even though this is a common practice in the potash field, it is not desirable. It does not provide individual trailing-cable overload protection or means for disconnecting the power at the point where the trailing cables are connected.

The alternating-current equipment, the size cables used, and the horsepower of the machines are listed in table 2.

TABLE 2. - Equipment data

Machine	Hp.	Cable size and conductors
Loader.....	75	No. 2 AWG, 3-conductor.
Undercutter.....	50	Do.
Jumbo drill.....	26	No. 4 AWG, 3-conductor.
Fan.....	5	No. 10 AWG, 4-conductor.

All trailing cables were type G, with grounding conductors. These cables were reconditioned in the underground shop. One man was assigned full time to

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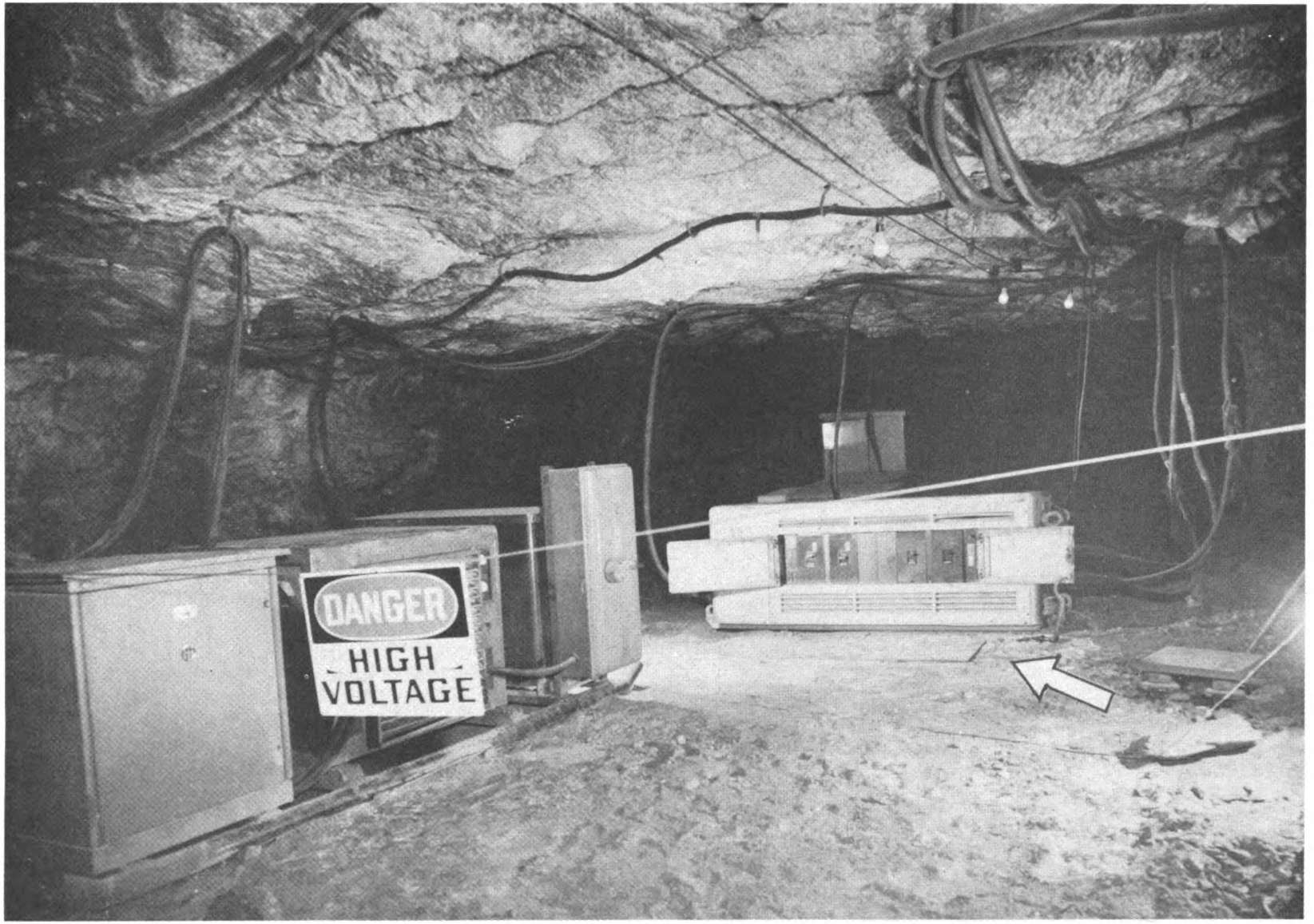

FIGURE 12. - Mine Power Center and Two Rectifier Units. Note the 4 Circuit Breakers of the Power Center and the Insulated Platform (arrow) for Use When 4,160-Volt Disconnects Are Pulled.

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this work. Figure 13 shows splicing and vulcanizing in progress. Two vulcanizers are used to speed up the procedure. When a cable is of the proper length, several sections are painted with light-color paint on the machine end. This can be observed on the cable mounted on the reel in the lower left foreground of figure 13. In using a machine, or unwinding a cable, the operator has a visual warning when the total cable length will be unwound off the reel. It prevents tearing cables or pulling them off the reel when the maximum travel distance has been reached.

Direct-current power at 250 volts nominal was supplied by selenium rectifiers which received three-phase, 60-cycle, 240-volt, alternating-current power. All rectifiers were operated in parallel. Conversion units, rated at 50 kilowatts each, were used. The conversion equipment was kept close to the working sections and provided direct-current power for the shuttle cars and machinery-moving trucks. Since all main haulage was done by belt conveyors, direct-current power was used only for secondary haulage, which utilized the shuttle cars. Cable-reel shuttle cars were used, which were also equipped with trolley poles having double-shoe harps. The trolley lines consisted of two parallel conductors of 4/0 AWG grooved figure 8 trolley wire. Both conductors, the positive as well as the negative, were mounted on insulators and kept above ground potential. Neither the positive nor the negative on the direct-current side of the conversion equipment was grounded. The direct-current system was checked periodically to determine any leakage to ground. The company feels that an isolated system of this kind is safer and more efficient because it eliminates interfering ground-circulating currents. Figure 14 shows the double-trolley installation. The loaded car, which is going to the unloading point, is in a position to change from cable to trolley-pole tramming, while the empty car going to the face will change to cable tramming. Individual nipping points are provided for each shuttle car. The shuttle cars were equipped with No. 2 AWG, two-conductor, type-W trailing cables. About 5 miles of double trolley line is installed in the mine.

GROUNDING AND GROUND-FAULT PROTECTION

As mentioned previously, two types of transformer connections were used - wye and delta - in distributing secondary 440-volt power. The neutrals of wye-connected transformer secondaries were solidly grounded, and grounding transformers were used to establish derived neutrals on delta-connected secondaries. The frames of all equipment, except equipment operated on direct-current power, were connected to the system ground through the power cables. The grounding conductors of both the secondary and primary distribution were interconnected. The underground and surface grounding conductors were connected to the main-plant grounding medium. Since there was no track haulage at this mine and since an isolated direct-current distribution system was used, there were no problems from ground circulating currents. Separation of alternating-current grounds by not making direct connections to direct-current frame-grounding conductors or the power return (track) is often advocated. Such a practice should minimize ground circulating currents in mines where both types of electrical energy are used and where the conversion equipment is operated with either the positive or negative side grounded. Nevertheless, many mining operations in the western part of the United States operate with

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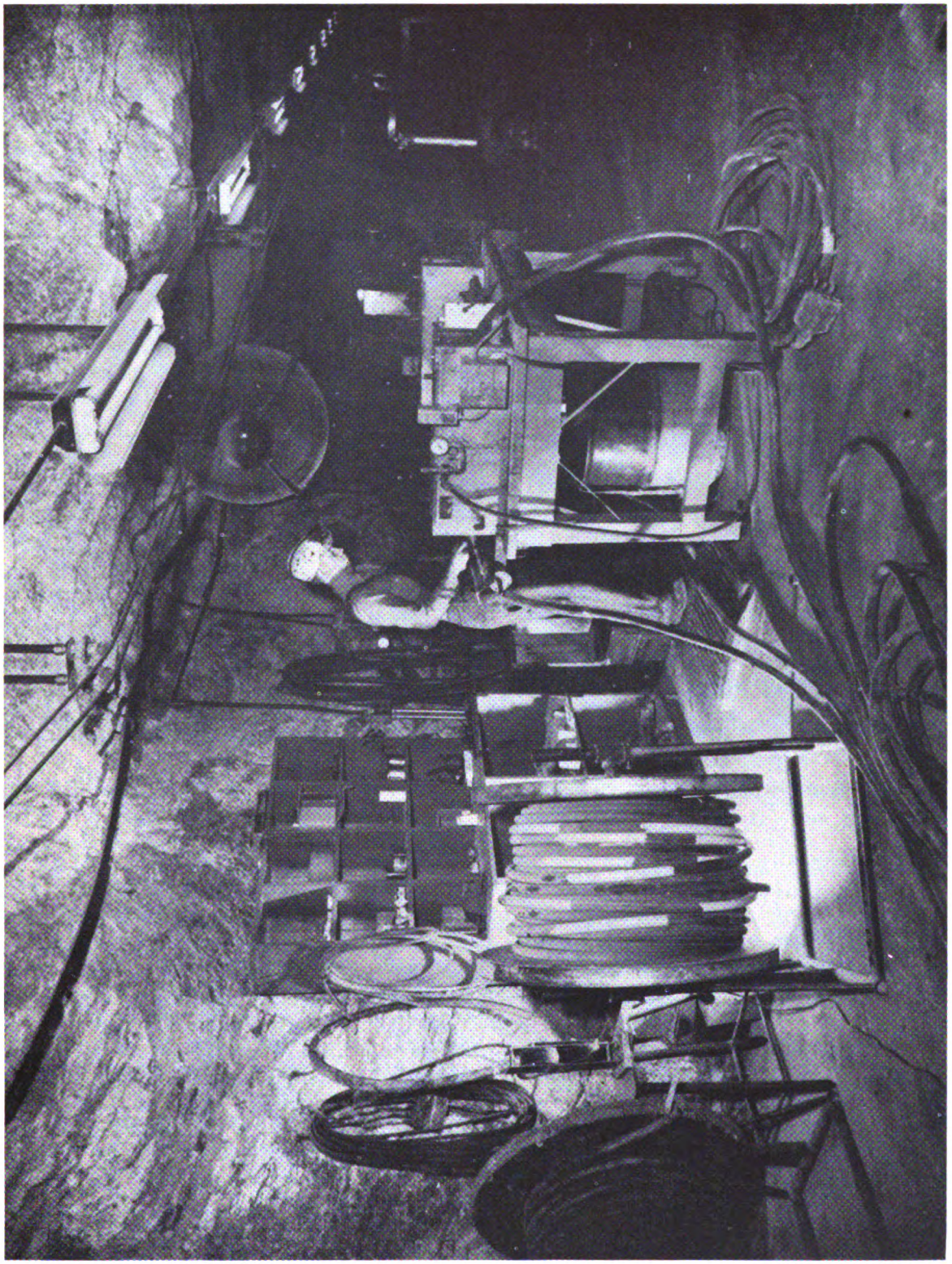

FIGURE 13. - Cable Vulcanizing Bench. Paint Marks on Cable Mounted on Reel Are Used to Indicate to Machine Operator When Maximum Cable Has Been Unwound From Machine Reel.

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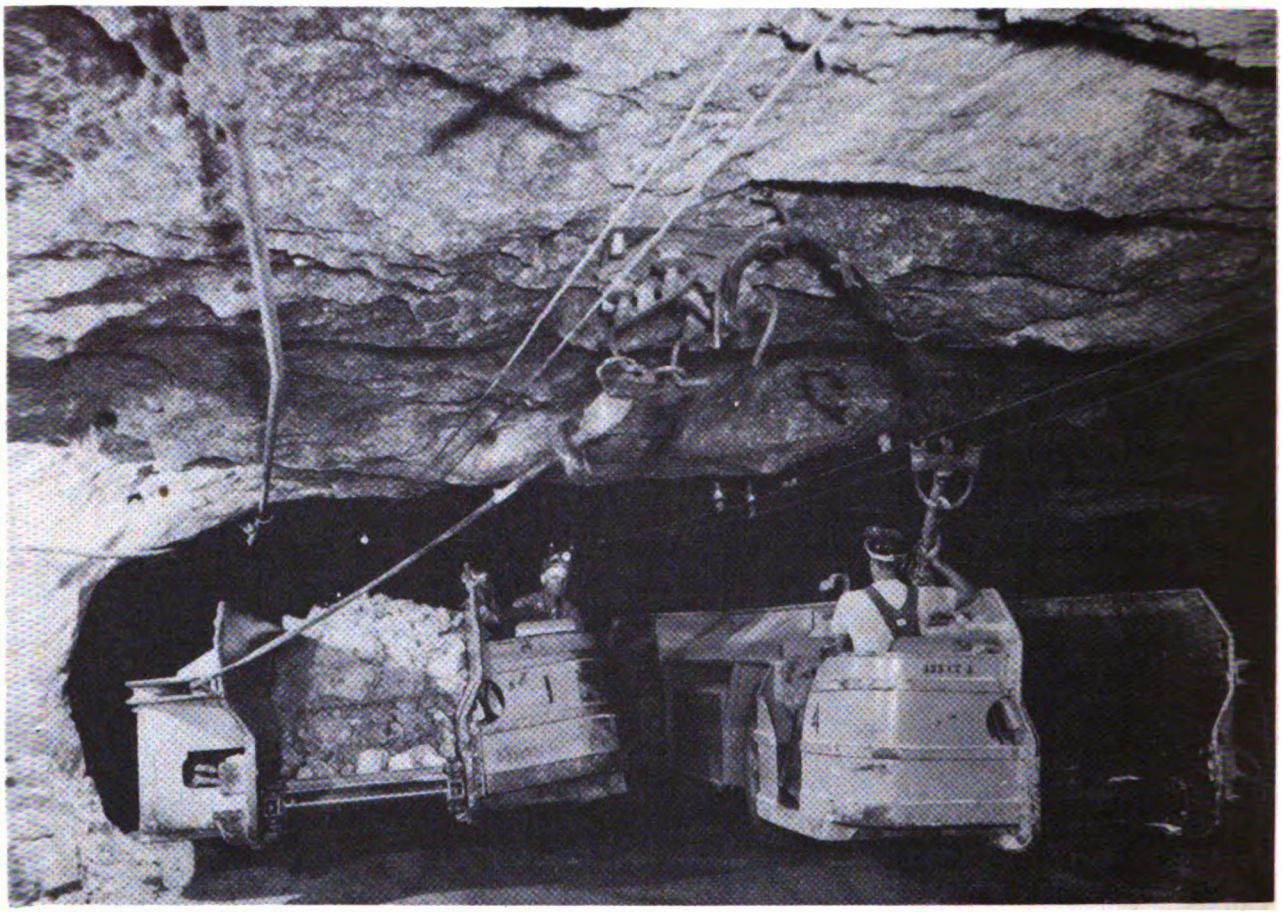

FIGURE 14. - Double Trolley Installation Showing Nipping Station for Cable and Use of Double-Shoe Harp.

integrated grounding systems and use both alternating- and direct-current power. In some instances it is felt necessary to have direct connections between the frames of face equipment and distribution centers of the direct- and alternating-current units. Such connections eliminate arcing between face equipment when contact is made. In essence, by interconnecting the frame grounding conductors, connections are made between the alternating-current grounding system and the direct-current power return. It is not within the scope of this paper to discuss in detail specific cases that may result in interference. It is sufficient to note that satisfactory operation is experienced by many operations having interconnected alternating- and direct-current grounding conductors. The subject property, however, has designed its distribution systems to operate independently. This has resulted in excellent, trouble-free operation.

Ground-fault protection was provided in the mine secondary alternating-current power circuits by two methods. Both methods are essentially the same, as both use a derived neutral. A zigzag grounding transformer with current limiting resistor is used to establish a neutral and provide ground-fault tripping current in one of the schemes. The current-limiting resistor is of

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such value that it limits the current to 5 amperes maximum. This resistor is rated for continuous operation at that current value. Figure 15 illustrates this method of tripping schematically. When a ground fault occurs in the machine, a flow of current is established in the frame-grounding conductor and the ground trip coil. At a current value of 3.5 amperes the ground trip coil actuates the tripping device. In this scheme of operation, the frame ground wire must be continuous for proper operation, since the trip coil is in series with it. Instantaneous tripping is obtained, and a rectifier-capacitor device is not employed.

The other scheme used to provide ground-fault protection is more or less an improvement on the first method. A current transformer of the ring or "doughnut" type is utilized to detect ground faults and provide tripping current. Figure 16 illustrates this method. In using the "doughnut" transformer, the power conductors to a given load pass through the opening of the core, while the frame ground conductor is carried on the outside, bypassing the transformer. The secondary of this transformer is connected to a relay inserted in the undervoltage trip circuit of the circuit breaker. If a fault from a power conductor occurs to the frame of any machine fed from such a circuit, the fault current, in passing through the ground-fault protective transformer core and returning via the ground wire, sets up a voltage in the secondary, owing to the unbalance. This voltage actuates the ground-current relay, which trips the circuit breaker. The ground-fault current again is limited to 5 amperes maximum, and tripping takes place at 3.5 amperes. The main advantage of this method is that it minimizes interference from ground circulating currents. Where direct-current-and alternating-current-powered equipment is used together in a section, and the direct-current power system has one side grounded, use of this scheme is recommended. Another advantage is that this method is more selective. In using it, only the breaker of the fault circuit involved is tripped, instead of the main breaker. The ring-type transformers on the power center shown in figure 17 can be seen underneath the circuit breakers. Four such transformers are used, one for each circuit breaker. They are mounted to the right of the circuit breaker, and the three power leads from the load side of the breaker pass through the core.

Overload or phase-fault protection for the individual secondary circuits is provided by the magnetic- and thermal-trip units of the circuit breaker. The ground-fault protective system previously discussed is not related in any way to phase faults. An overload or unbalance due to a phase fault (contact of two power conductors) will not actuate the ground fault relay, unless a ground-fault condition is also present. The ground-fault protection discussed using a ring-type transformer is referred to as operating on an unbalance principle. It should be pointed out that the term "unbalance" refers to the current flowing in the conductors enclosed by the core of the current transformer. For instance, in a phase fault or a single-phase condition, where one power conductor is open, a definite unbalance exists. However, in these instances there will be a current balance in the wires; that is, the current summation through the core is zero. Therefore, current will not flow in the secondary of the "doughnut" transformer, and the ground-fault relay will not be actuated. To establish a potential difference in the secondary winding of the ground-fault protective transformer, it is necessary to have current flow

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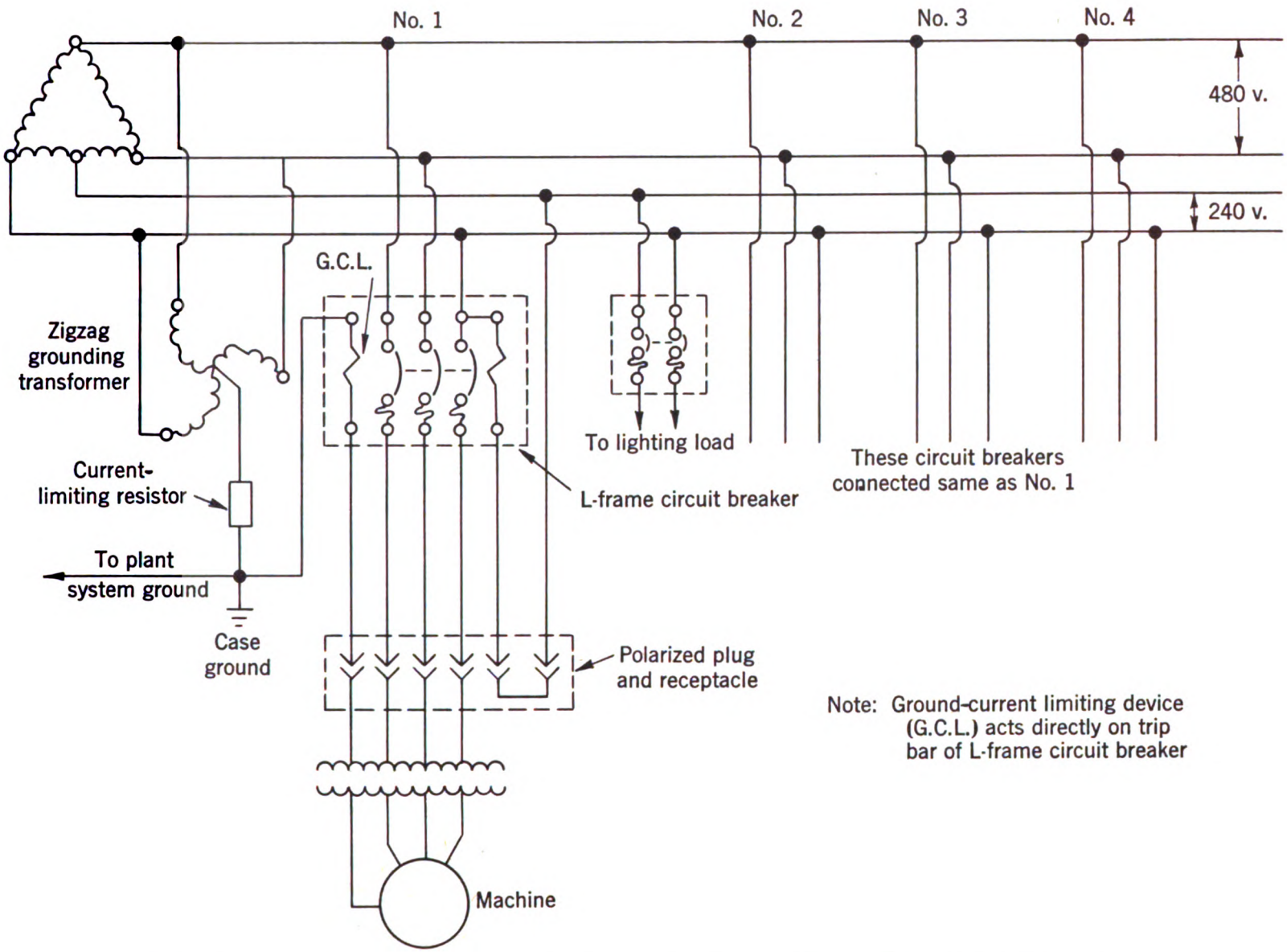

FIGURE 15. - Schematic Diagram of Ground-Fault Protection, Showing Transformer Connections, Grounding Transformer, and Ground-Current Relay.

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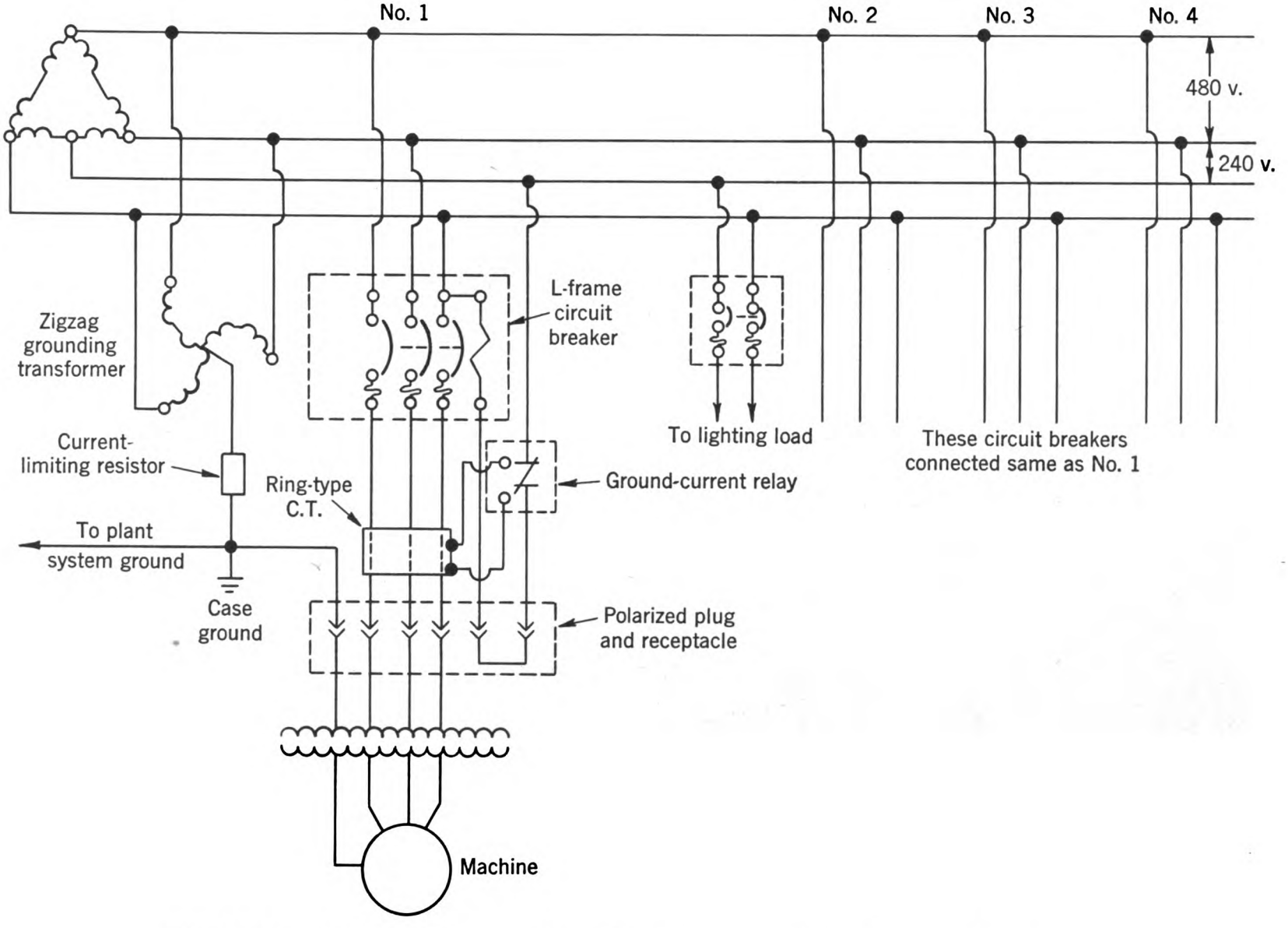

FIGURE 16. - Schematic Diagram of Ground-Fault Protection, Using Ring-Type Transformer.

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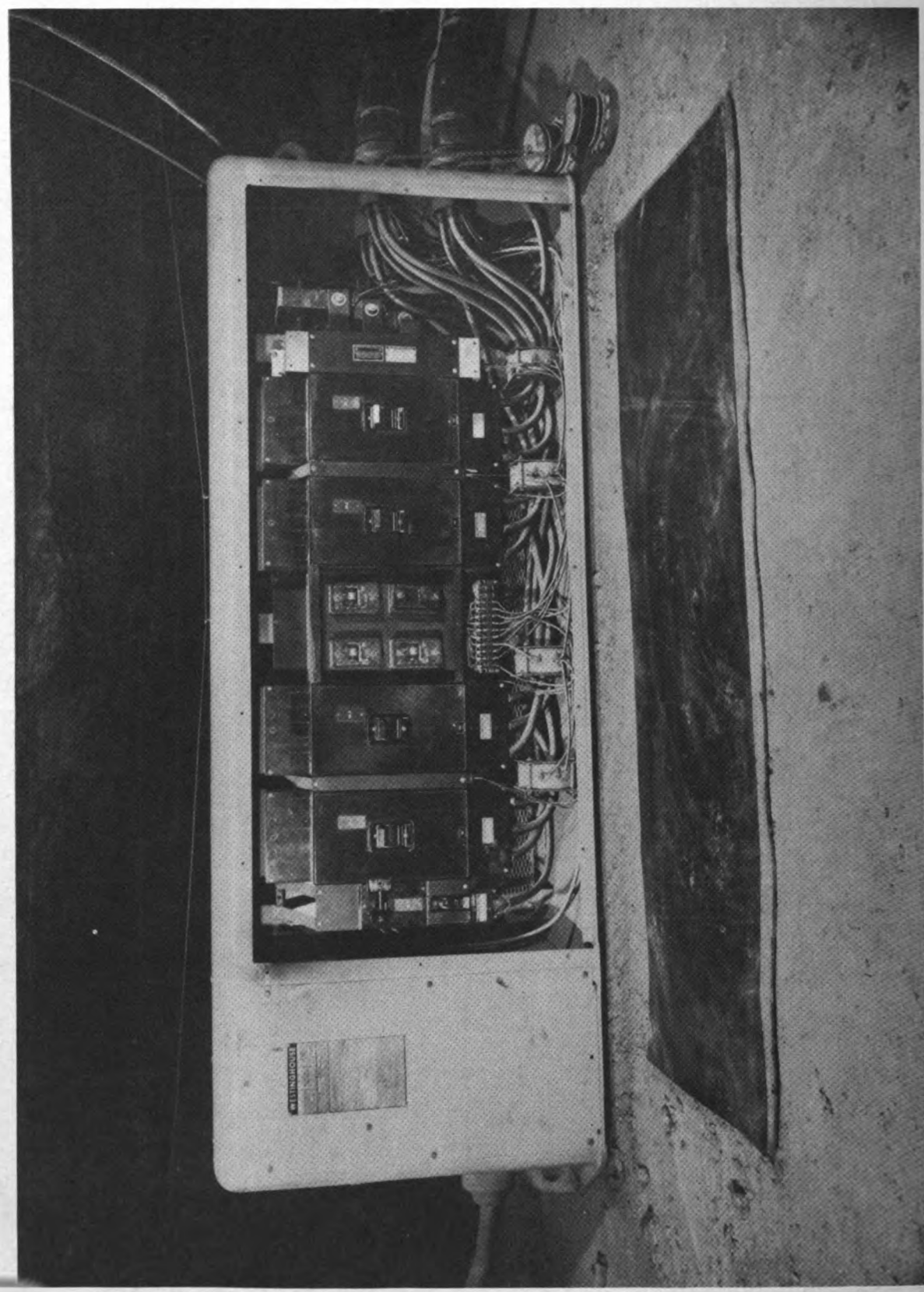

FIGURE 17. - Power Center With Cover Removed. (A ring-type ground fault protective transformer is mounted beneath each circuit breaker).

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in the grounding conductor or another path outside the transformer aperture. Such a current, if due to a ground fault in the equipment served by the circuit, will obviously result in a current unbalance over the power conductors enclosed by the current transformer. As in the previously described scheme, continuity of the frame ground wire is essential for proper operation. Periodic checks are made for frame-grounding conductor continuity and proper operation of ground fault relays.

The ring-type, transformer, ground-fault protective system can be used on power systems utilizing transformers with wye-connected secondaries. At this property ground-fault protective relays were not normally used in conjunction with secondary 440-volt power delivered from wye-connected transformers. However, welding equipment was served by switchgear equipped with 5-ampere ground trip devices. The welding machine shown in figure 18

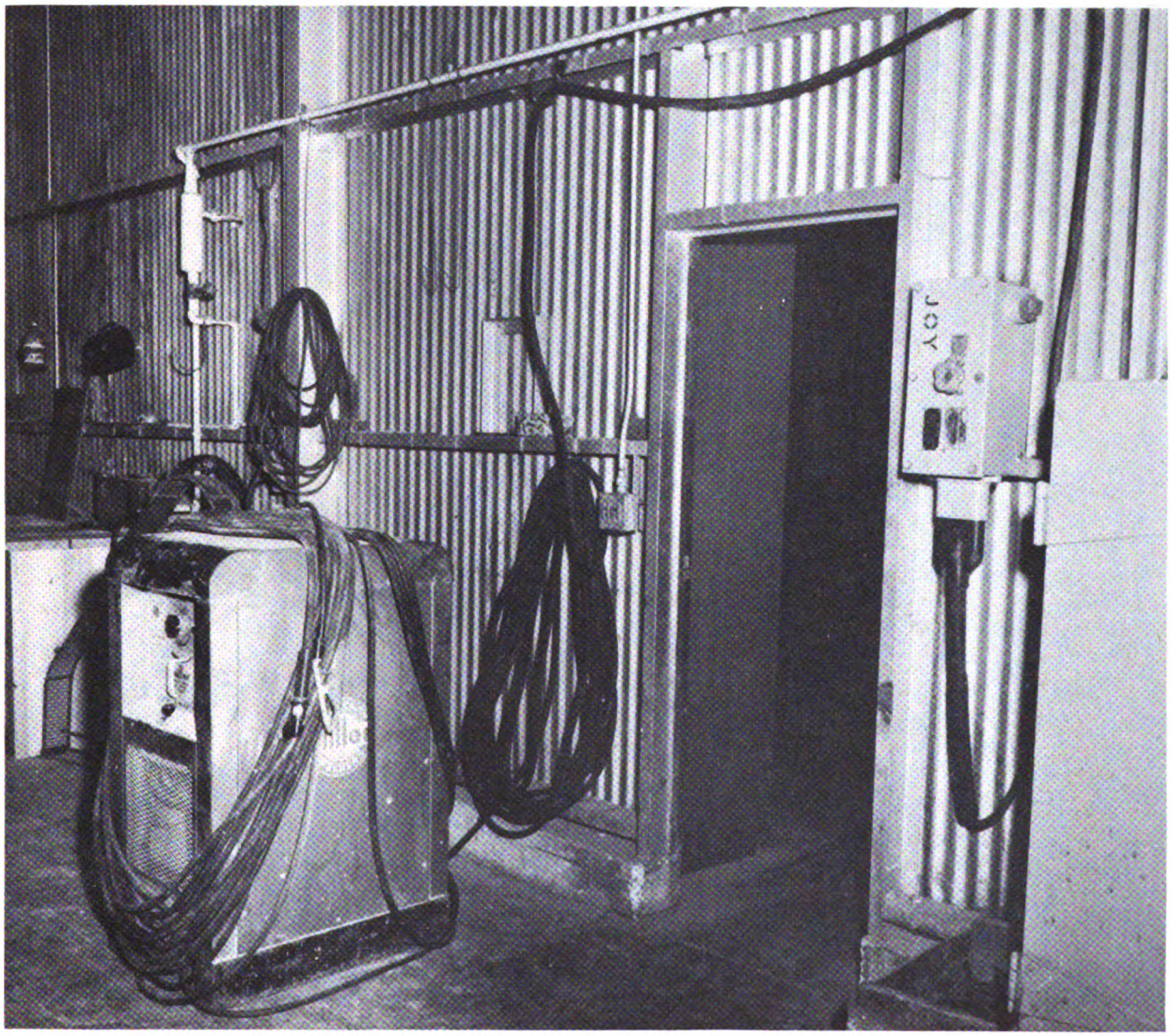

FIGURE 18. - Welding Machine Connected to Power Supply.

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illustrates a typical installation. The same type of switchgear is provided throughout the plant for connecting welding machines to the power supply. The isolation of phase as well as ground faults on the equipment and circuits served by wye-connected transformers, with solid grounded neutrals, was accomplished by the overload devices. Because of the numerous equipment involved, immediate isolation of a fault by the overload devices is obviously advantageous from the selectivity point of view. The severity of damage to equipment under such protection may be at times greater than if ground-fault devices are used. However, from the operational and practical consideration, immediate isolation and locating of faults is much to be desired. With the

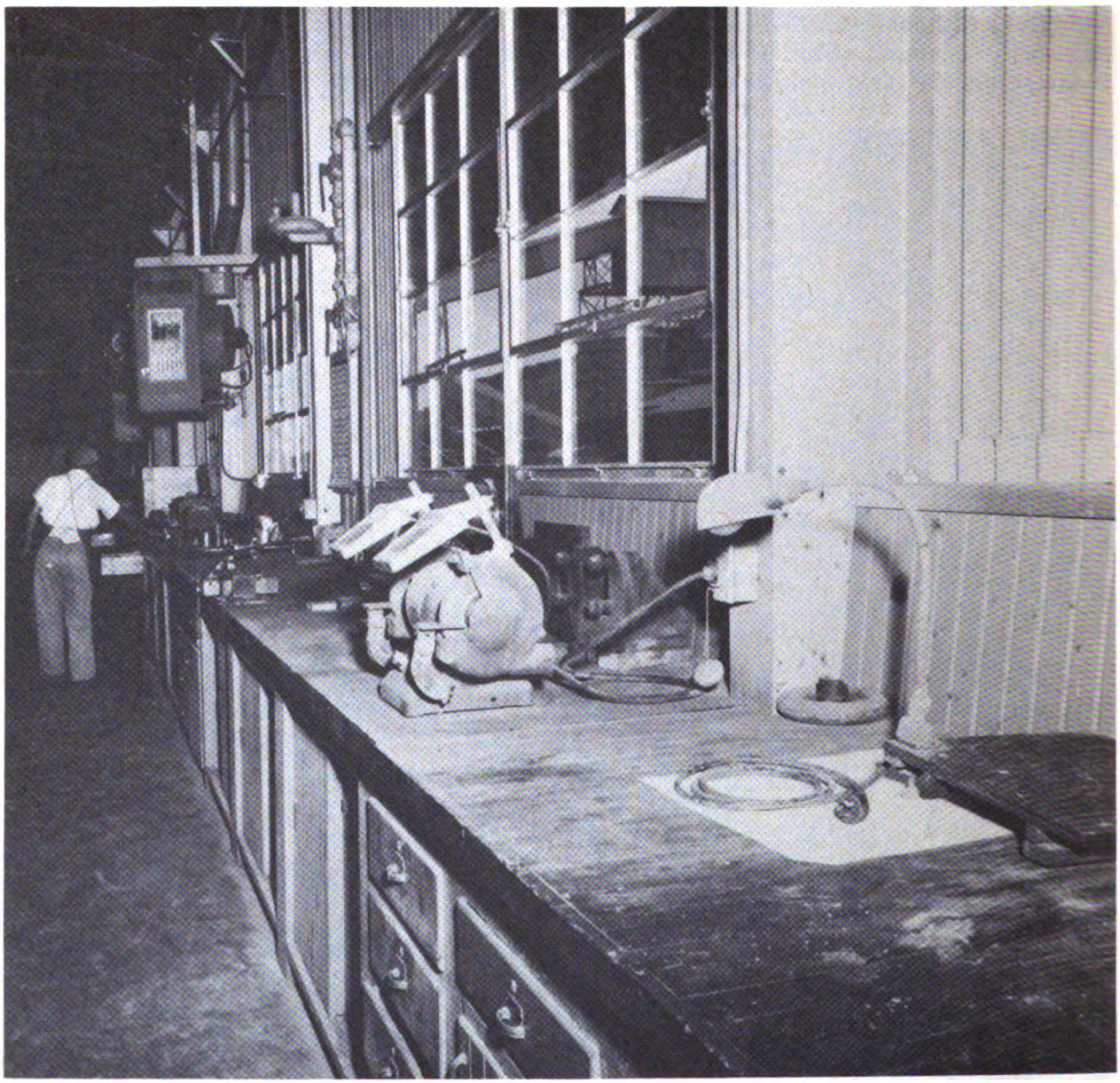

FIGURE 19. - Workbench in Machine Shop. Polarized Outlets and Three-Pronged Plugs for Grounding Frames Are Provided on 110-Volt System.

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solidly grounded wye neutral used, such isolation of faults was accomplished satisfactorily by the overload devices.

All 110-volt, single-phase outlets throughout the plant are such that only three-pronged plugs can be used. Thus, when stationary, portable, or handheld equipment is connected to an outlet, the frame is automatically grounded through the third prong. Figure 19 shows a section of the workbench in the machine shop. An outlet can be observed in the foreground, to which the grinder is connected. It should be pointed out that the portable writing board with the attached lamp is also equipped with a three-conductor cable. The metal parts of the lamp, the shade, the flexible stem, and the base are grounded through the third conductor when the lamp cord is connected to the receptacle. All 110-volt lines were in conduit, and all receptacles were in metal boxes provided with caps to prevent dust from accumulating in the outlet, when it was not in use.

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